
Chapter 9

Quality Control: Concept, Control Plan, Procedures

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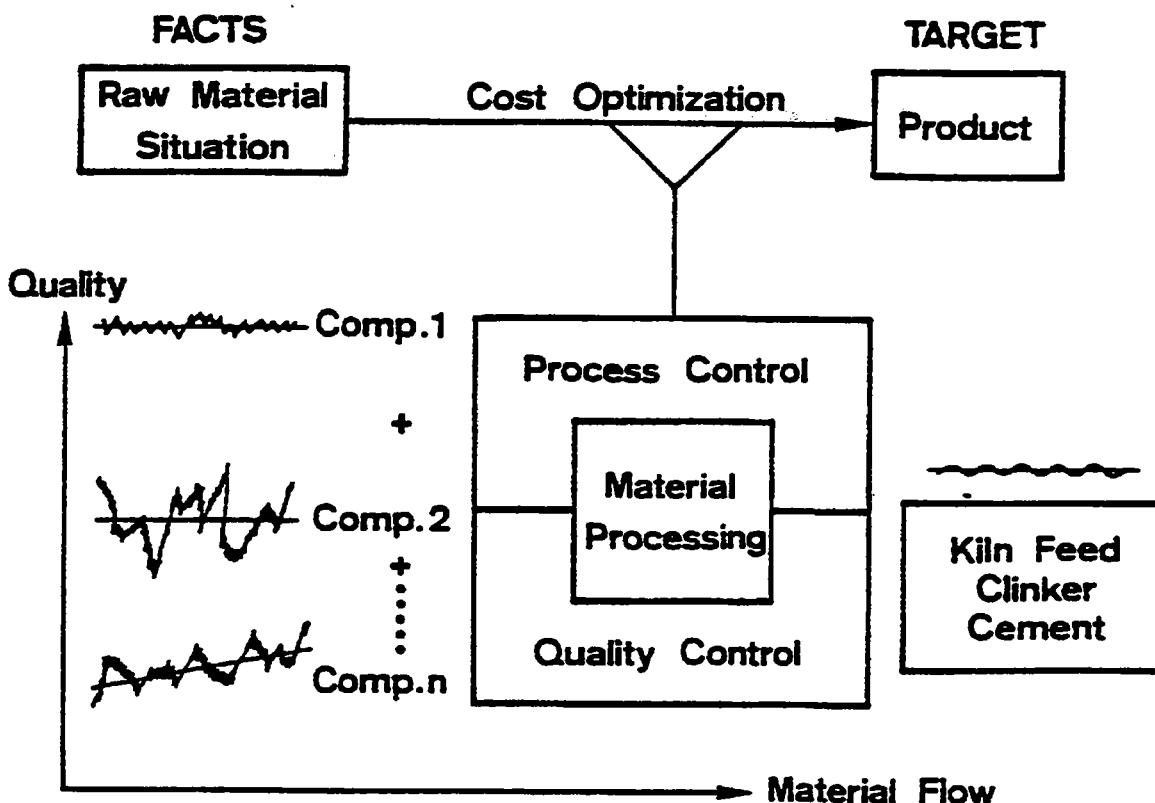
1. INTRODUCTION

The principle aim of this paper is to highlight aspects concerning quality concept, plans and procedures that meet with today's process and market requirements. It is certainly not possible to make a generally valid statement as to the most suitable way of carrying out quality control and to define the most adequate degree of sophistication and automation for every plant. This must be part of the quality planning in each individual company and plant.

2. QUALITY CONTROL CONCEPT

Quality control normally complements the process control, with the aim being to monitor the product quality at the different production stages, so that the required quality level is finally achieved.

Fig. 1 **Quality Control.**



Tested properties may include chemical composition, moisture, granulometry as well as other properties relevant to the specific material.

Special procedures are being applied for the delivery control of combustible or non combustible waste materials.

3. CONTROL PLAN

The control plan shows how the general control concept for each raw material, intermediate and final products is to be realised.

A detailed control plan for quality control is set up by a thorough analysis of the following questionnaire:

- ◆ What should be examined?
- ◆ What information is required for the control?
- ◆ How often must the test be performed?
- ◆ How accurate must the result of the testing be?

In every particular plant, the concept of quality control, with its objectives and targets, its detailed programme of testing , its technical features of the control system and its decision criteria should be carefully formulated in written and graphical form.

Thereby, the quality control procedure is clear, and adaptation to changed situations, whenever necessary, is facilitated. The enclosed figures 2, 3 and 4 are examples of such documentation.

Fig. 2 Inspection and Testing Plan.

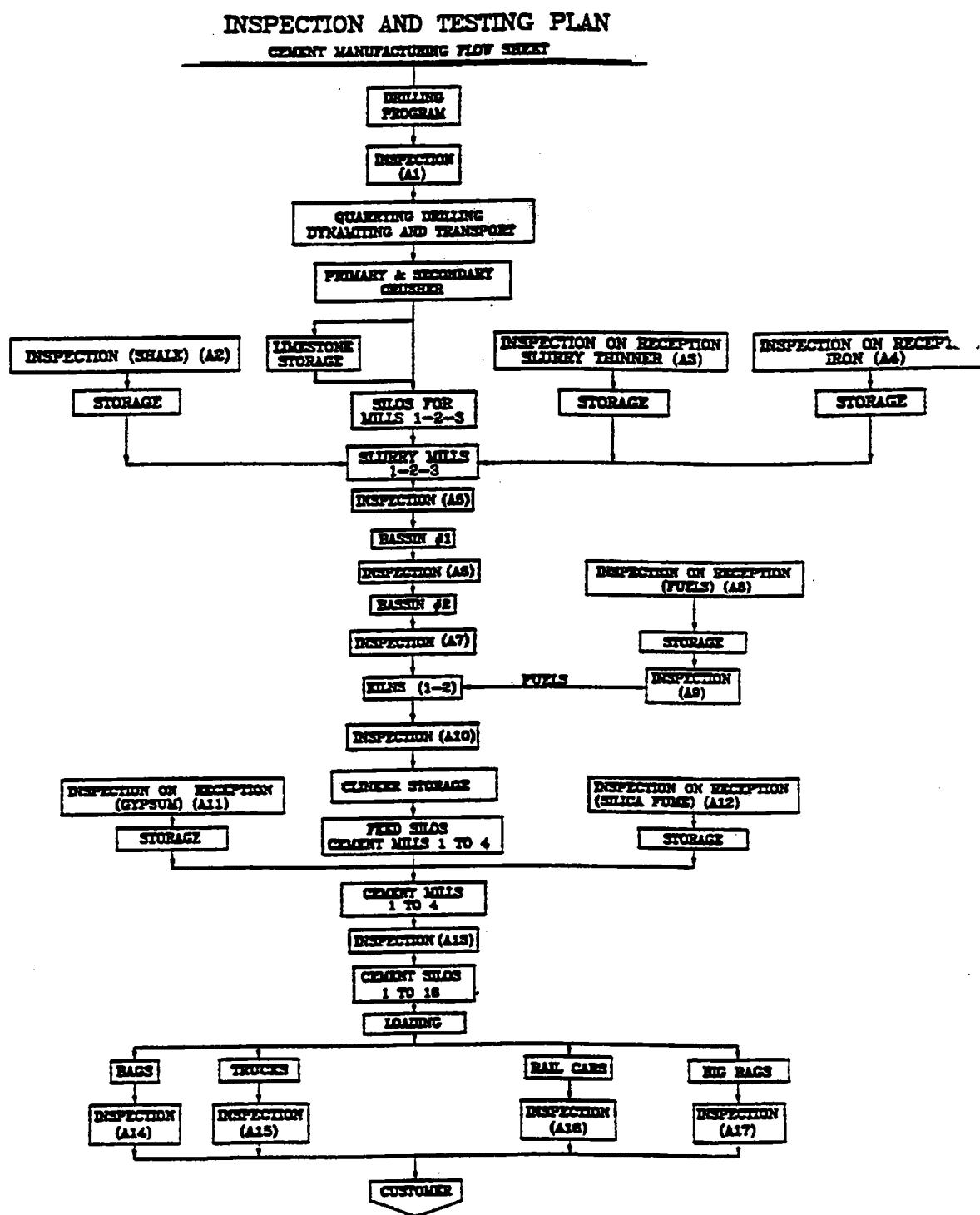


Fig. 3 Quality Control Plan (extract).

No	Material	Sampling Point	Sampling	Sampling	Sample	Test Frequency	Tester	Tests	Data Processing	Objective
8	Gypsum	Trucks (ship arriv.)	spot	1/y	AdD	1/y	AdD	SO ₃ , insoluble, humidity		Quality assurance
9		Cement mill	spot	1/15 d	MdT	1/15d x/m	AdD AdT	Humidity SO ₃	SR SR	Prod. control Quality assurance
10	Raw meals	before elevator to silos (M1, M2)	screw samp. with mixer	1/h	MdT	1/h 1/2 h 1/4 h 1/8 h x/d	MdT AdT AdT AdT AdD	R150µm, R75µm XRF-tablett (LS, SR, AR) Titration Humidity XRF-tablett, humidity, LOI	SR SR SR SR DSR, MR, MSR	Mill control Blending contr. Prod. control Quality control
11	Kiln feeds	before elevator to kiln (H1, H2)	screw samp. with mixer	2/h	MdT	1/2 h 1/4 h x/d	MdT AdT AdD	R150µm, R75µm, XRF-tablett (LS, SR, AR) XRF-tablett, LOI; kiln 2: XRF-perl	SR SR DSR, MR, MSR	Quality control Quality control Quality control
12	Hot meals	lowest cyclon (H1, H2)	spot	2/w	MdT	2/w	AdD	XRF-tablett (Cl, Alk, SO ₃) LOI	SR	Process control
13	Clinkers	Kiln outlet (H ₁ , H ₂)	spot	1/h	MdT	1/h x/8h x/d	MdT AdT AdD	Literweight Free lime XRF-perl, free lime	SR SR DSR, MR, MSR	Process control Process control Quality control

Fig. 4 Plan Qualite.

SOCIETE : USINE :		PLAN QUALITE						Feuillet n° 4.7.2	
ATELIER	NATURE PRODUIT	VENANT DE	ALLANT VERS	Date d'effet du feuillet : OCTOBRE 1989					
BROTEAGE CIMENT	CIMENT	BROTEURS C1 OU C2	SILOS DE STOCKAGE CEMENTS FINIS	Annule et remplace le feuillet n° du :					
PRELEVEMENT	RELEVE	VISITE	ENDROIT	FREQUENCE			QUANTITE	RESPONSABLE	
MANUEL			AVANT PNEUMEX	TOUTES LES 2 HEURES SUR CHAQUE BROTEUR			1 LITRE	REUNIER	
OPERATEUR	NATURE	METHODE		S E U I L S					
			LIMITE MINI	Seuil alerte		LIMITE MAXI	OBJET	SUPPORT	
CONTROLES	REUNIER	SURFACE SPECIFIQUE "BLAINE" (SSB REPRESENTE LA VALEUR DE CONSIGNE FIGURANT POUR CHAQUE QUALITE SUR LA FEUILLE "REGLAGES BROTEAGE CIMENT")	20	SSB - 200	SSB - 100	SSB + 100	SSB + 200	REGLAGE DU BROTEUR POUR L'OBTENTION DE LA SURFACE SPECIFIQUE "BLAINE" DE CONSIGNE	FEUILLE DE MARCHE DU BROTEUR
ANOMALIES	DEVIATIONS - sortie des seuils d'alerte -			DEFAUTS - sortie des limites -					
	PREVENIR	ANOMALIES	ACTIONS	PREVENIR	DEFAUTS	ACTIONS			
	SURFACE BLAINE	MODIFICATION REGLAGES SEPARATEUR ET/OU BROTEUR.		SURFACE BLAINE	1) MODIFIER REGLAGES SEPARATEUR ET/OU BROTEUR 2) PRELEVEMENT D'UN AUTRE ECHANTILLON APRES : UNE DEMI-HEURE AU C1 - SI CONFIRMATION SORTIE DES LIMITES: 3) PROCEDER A VERIFICATION COMPLETE DE L'INSTALLATION(SEPARATEUR, VENTILATION) 4) POURSUIVRE PRELEVEMENTS ET MESURES PERIODIQUES DE SURFACE "BLAINE". LIMITATION A 3 HEURES DU TEMPS DE MARCHE DE L'INSTALLATION DANS DES CONDITIONS ANORMALES				

4. GENERAL PROCEDURES AND CONTROL PARAMETERS

The following sections give a general survey of the most important control positions for raw materials, intermediate and final products in a cement plant (emphasis on dry process). Reference is being made to the schematic plant layout in figure 5.

Fig. 5 Cement Plant - Material Flow.

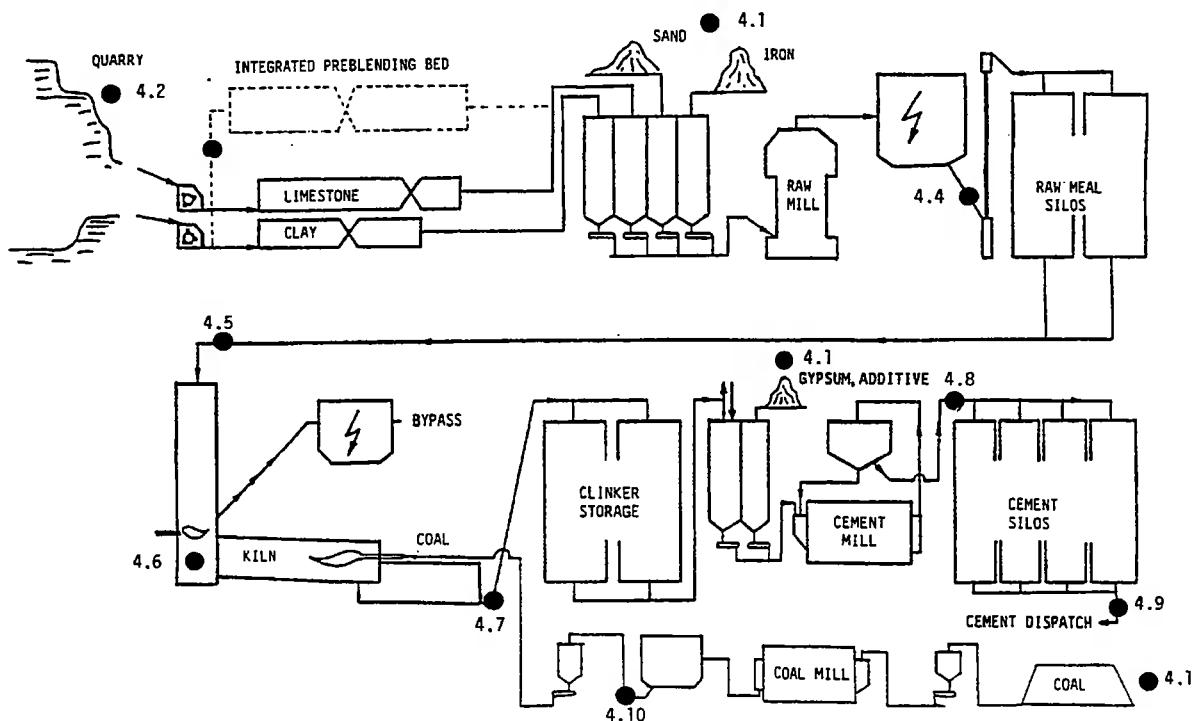


Fig.6 Sampling Tower

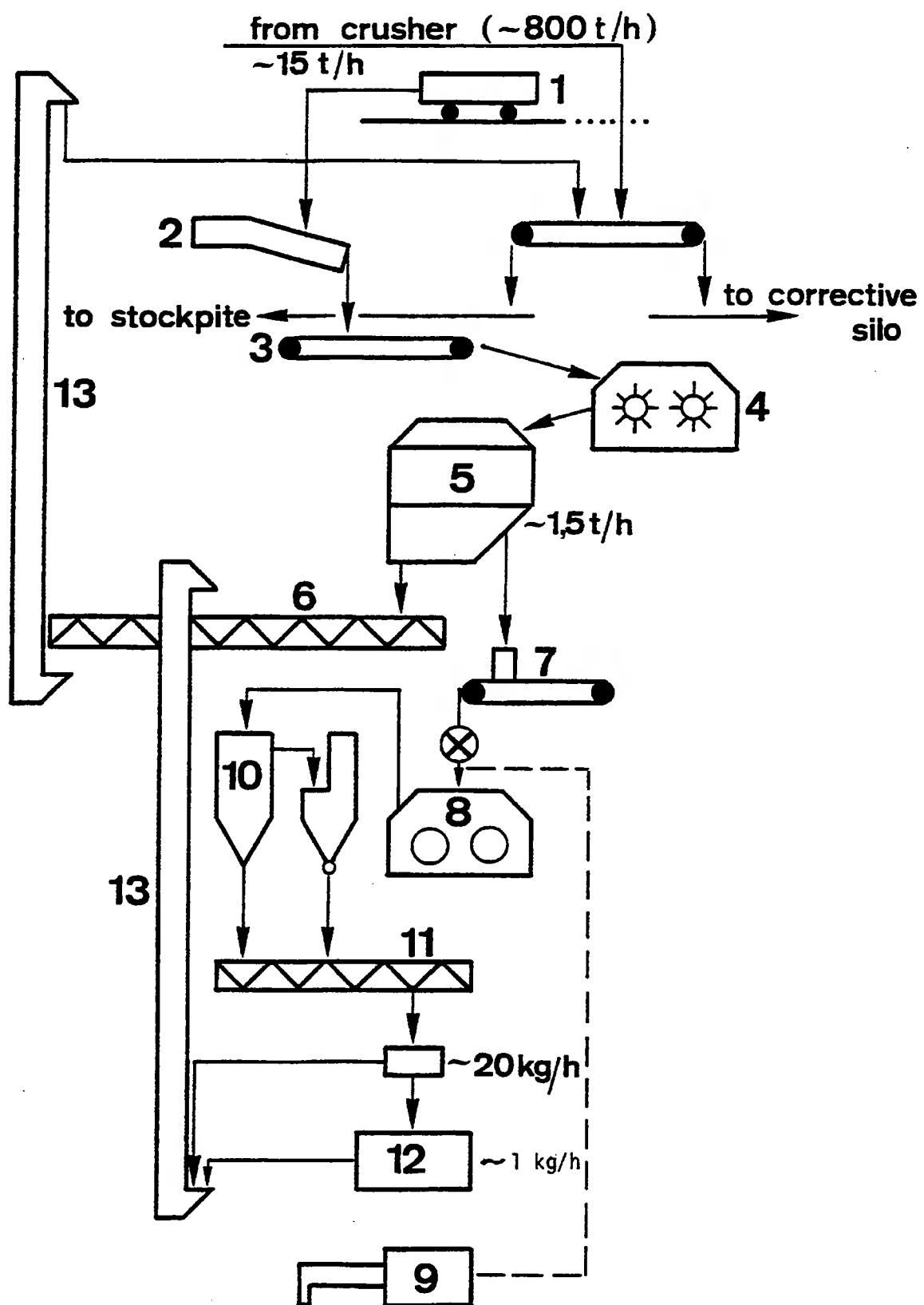
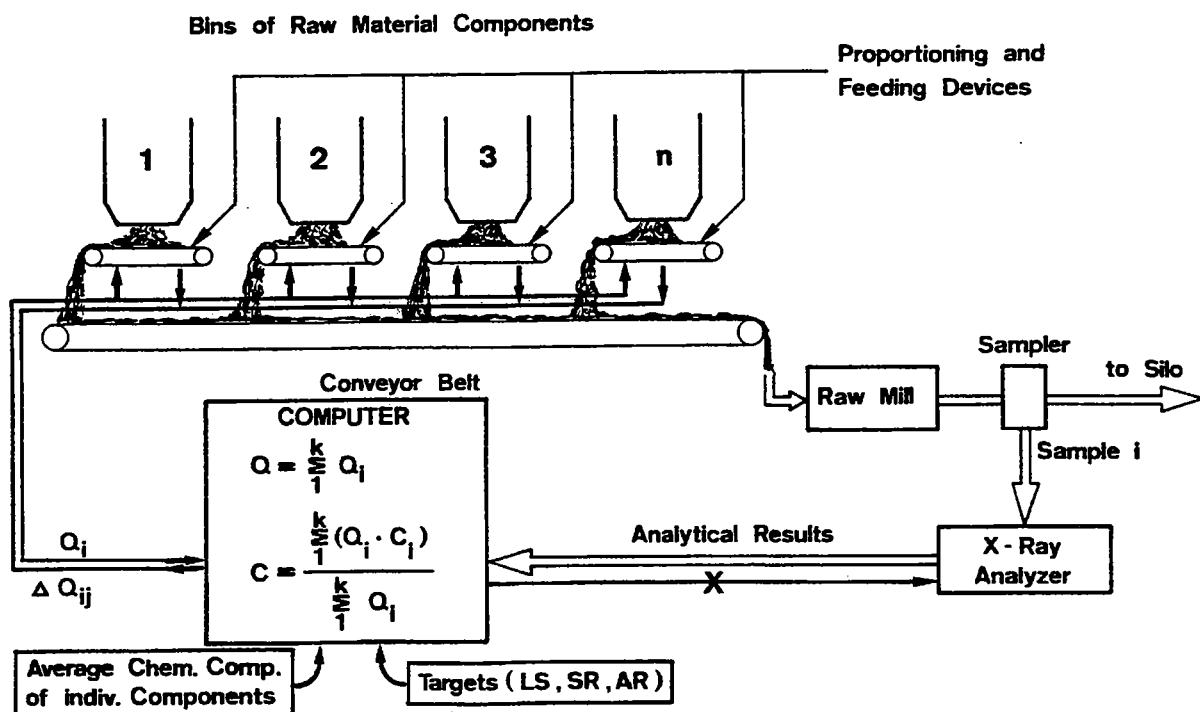


Fig.7 Automatic on-line Control of Raw Mix Composition



In a concise form, the purpose of control, typical control parameter and typical techniques for sampling and testing are given, as well as additional comments where appropriate. In view of the large variety of materials involved, of plant layouts, processes, sampling and testing methods, the survey does not apply to all cases and does not attempt to be complete.

4.1 Supplied Materials

Purpose

The testing of supplied materials such as raw mix correctives, gypsum, mineral additives (slag, fly ash, etc.), combustibles, serves to verify their compliance with delivery contracts and hence their suitability for the anticipated utilisation.

Procedure

The extent of sampling and testing varies strongly, depending on type of material, its source and delivery contracts. Whenever possible, sampling should be done from conveyed material rather than from trucks or stockpiles.

4.2 Quarry

Purpose

Control of the materials composition prior to excavation enables selective quarrying to achieve

- ◆ correct composition of (integrated) stockpiles
- ◆ medium to long-term uniformity of stockpile composition
- ◆ optimum utilisation of materials and equipment.

Control parameter

Chemical composition, often with emphasis on specific elements such as SiO₂, MgO, SO₃, alkalis, C1.

Sampling

Usually blast drill hole dust.

Process interaction

Based on manual or computerised data evaluation:

- ◆ selection of area to be blasted
- ◆ selection of (blasted) material to be fed to the crusher.

Alternatives

Information on the chemical structure of the quarry can also be obtained from analysis of crushed stone by online bulk material analysis (neutron activation technology) or mechanical sampling followed by conventional analysis.

4.3 Pre-blending

Purpose

Blending of raw components on (integrated) pre-blending stock piles to a given target composition.

Control parameter

Chemical composition, moisture.

Process interaction

Selection and dosage of material fed to the crusher.

Procedure

Today, two different concepts are applied to monitor and integrate the composition of the material fed to a pre-blending bed.

- ◆ **Sampling tower**

Mechanical sampling of 1-2% of the materials feed and subsequent steps of sample comminution, drying where required, and splitting in a sample tower (Fig. 6), to receive typically 1 kg of fine, sample per hour for analysis.

- ◆ **Bulk material analysis**

Continuous chemical analysis of the entire or partial materials stream by means of a bulk material analyser applying the technology of prompt gamma neutron activation analysis PGNAA (see reports MA 89/3702/E and VA 92/5975).

4.4 Raw Meal

Purpose

The raw meal control serves the following objectives:

- ◆ Blending of components to obtain the target composition of raw meal and clinker.
- ◆ Achievement of target meal fineness to obtain an appropriate clinker burnability.
- ◆ Achievement of a sufficient uniformity which, together with the homogenisation in the subsequent silo, results in a high kiln feed uniformity.

Control parameters

- ◆ Chemical analysis, and parameters derived thereof such as lime saturation, silica ratio, alumina ratio, potential clinker mineral phases C₃S, C₃A, etc.
- ◆ Fineness, usually in terms of sieve residues (e.g. on 200 µm and 90 µm sieves)
- ◆ Residual moisture content.

Process interaction**Adjustment of feed rate to the mill**

off-line: manual, based on mix calculation

on-line: automatic, based on blending programme (fig. 7).

To be observed: Dynamics of grinding process (retention time, internal circulation, dead time of analysis).

Sampling

Usually, automatic compositing sampling from a chute or an airslide is applied. Standard samplers, typically screw samplers or airslide samplers are used, with or without integrated mixing facilities.

Frequency

Typically every ½ to 2 hours.

Testing

Chemical composition:	X-ray fluorescence complexometric titration carbonate titration
Fineness:	Sieving, laser granulometer

Alternative techniques

Bulk material analysis (PGNA technology) can be applied to continuously monitor the composition of the mill feed or the raw meal.

Comments

The set points of the raw meal composition have to be such that the target composition of the clinker is being obtained. Allowance has therefore, to be made for:

- ◆ the coal ash incorporation in clinker
- ◆ the kiln dust absorption in the raw mill (kiln dust composition can significantly deviate from the kiln feed composition)
- ◆ the discarding of kiln dust
- ◆ systematic errors in sampling and analysis.

The primary target is the clinker composition. If any of the above factors change, the raw meal set-point has to be adjusted accordingly.

A practical example for a case where such changes have evidently occurred after a long kiln stop, but without any reaction on the raw meal set point, is given below.

	Plant with oil firing Monthly average values.		
	Raw meal LSF	Clinker LSF	Clinker CaO _F
December	99.1	98.1	1.4
January	98.0	96.8	0.8
February	97.8	97.1	0.9
Kiln stop			
June	96.0	99.7	2.1
July	97.0	100.0	1.9
August	97.2	100.4	2.1

As an illustration for the compositional range of industrial clinkers, the lime saturation, silica ratio and alumina ratio of the clinkers produced in the Holderbank group are graphically displayed in figures 8 and 9

Fig. 8 Clinker Composition (Alumina).

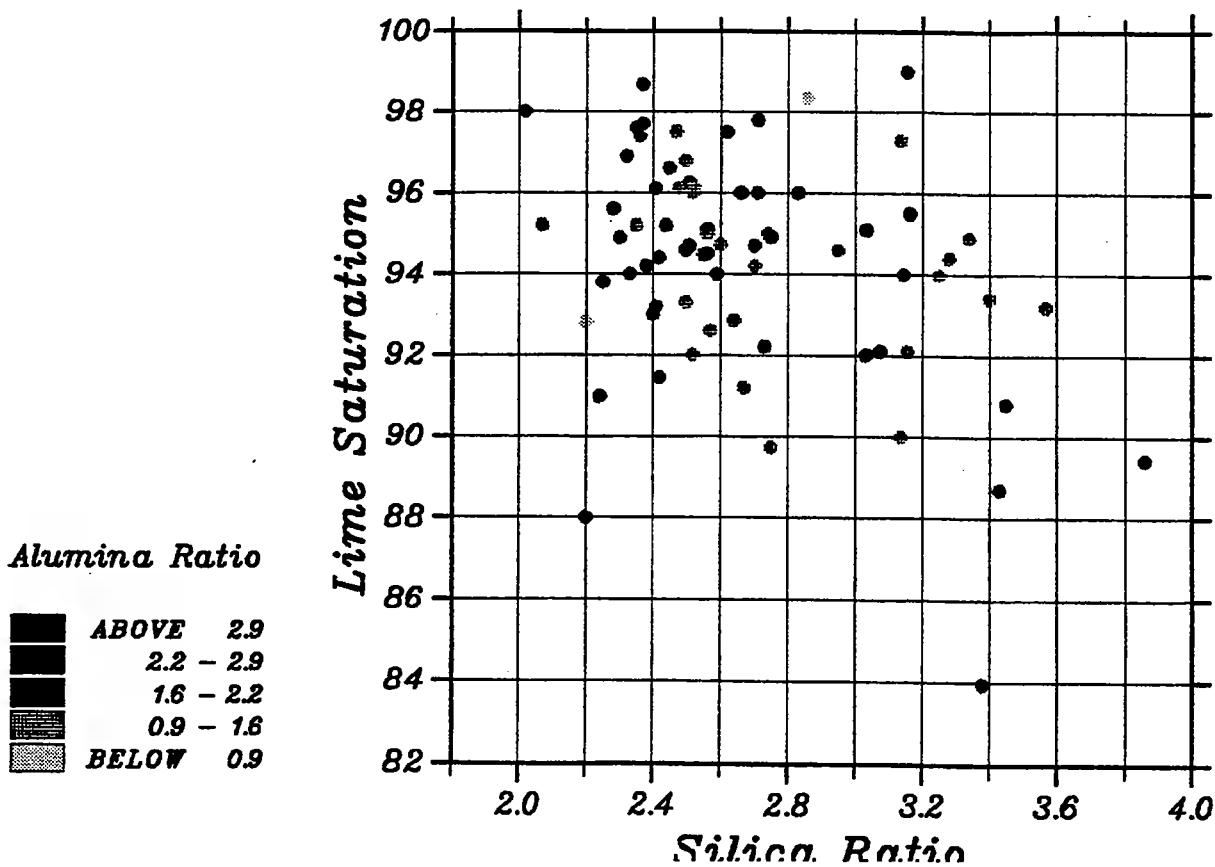
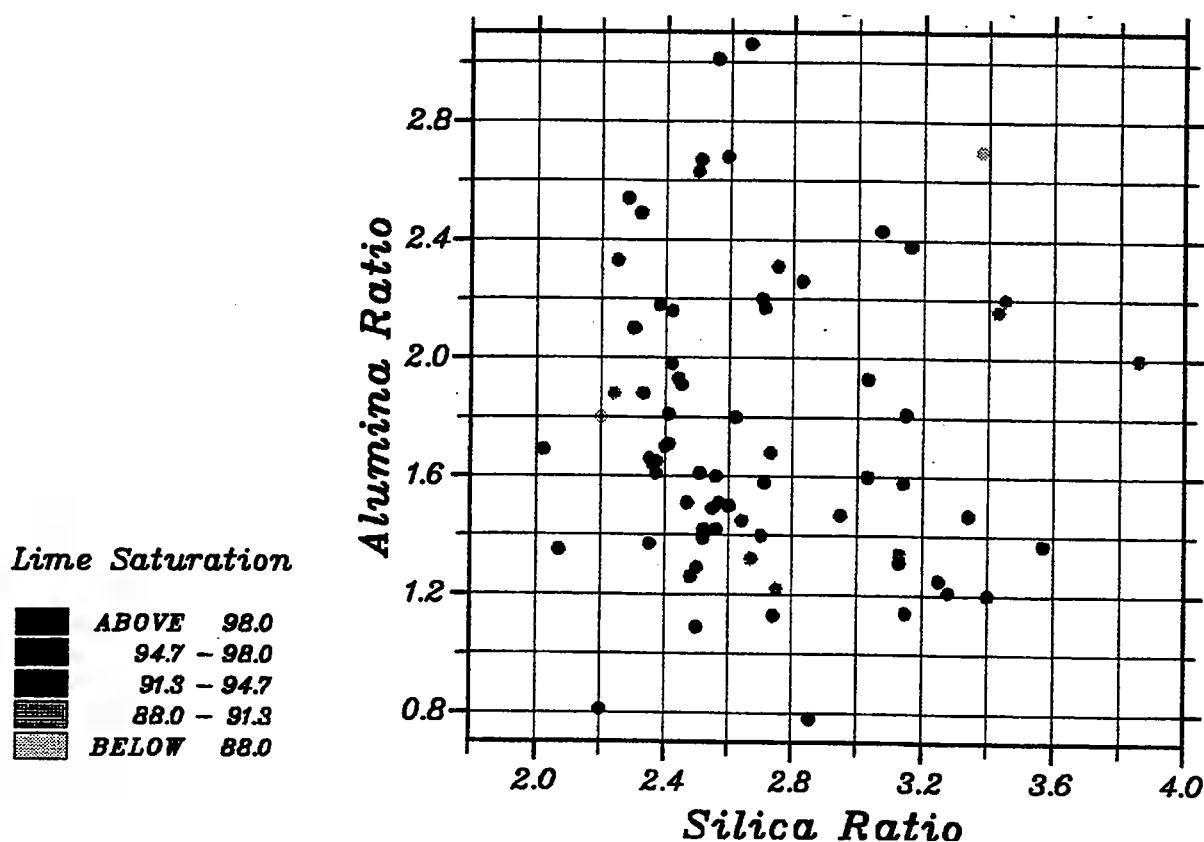


Fig. 9 Clinker Composition (Lime Saturation).



4.5 Kiln Feed

Purpose

Kiln feed control has only informative character. It provides guideline information (LS, SR, AR) for kiln operation on currently processed material, as well as indications on the raw material blending and homogenising efficiency. Figure 10a and 10b are an illustration of a poor kiln feed uniformity, caused by poor raw mill control and low homogenisation silo efficiency.

Fig. 10a Kiln Feed.

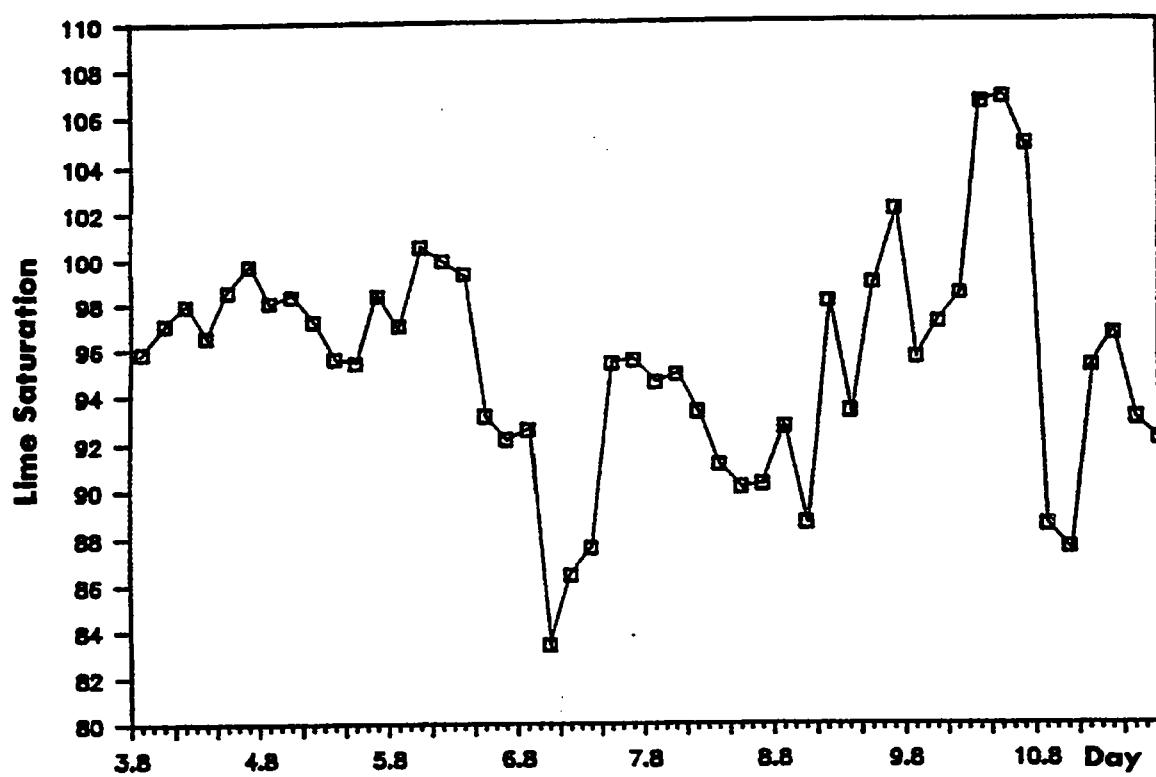
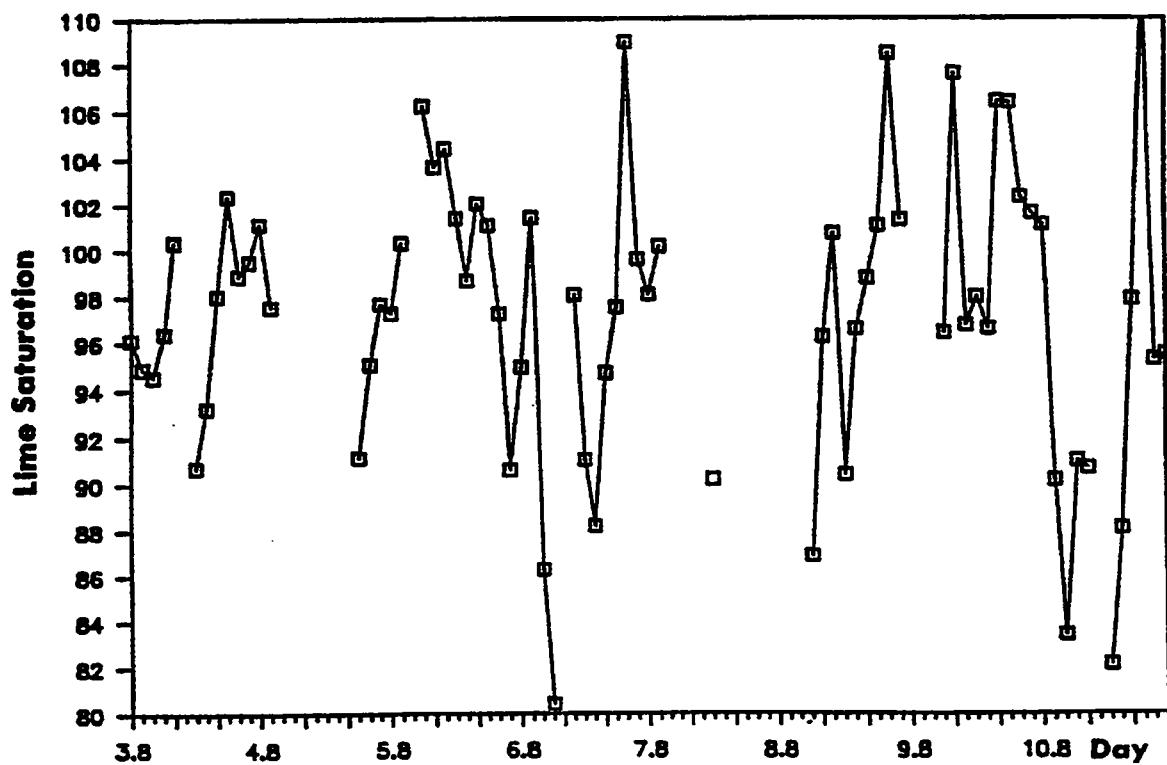


Fig. 10b Raw Meal.



Procedure

Usual sampling positions are in front of a kiln feed airlift (e.g. with screw sampler) or from a belt weigh feeder (manually). Sampling frequency varies according to the plant specific requirements form e.g. 2 samples per shift to no control at all. Normally, the same chemical and fineness parameters are determined as for the raw meal.

4.6 Hot meal

Purpose

The control of the hot meal composition can have various objectives:

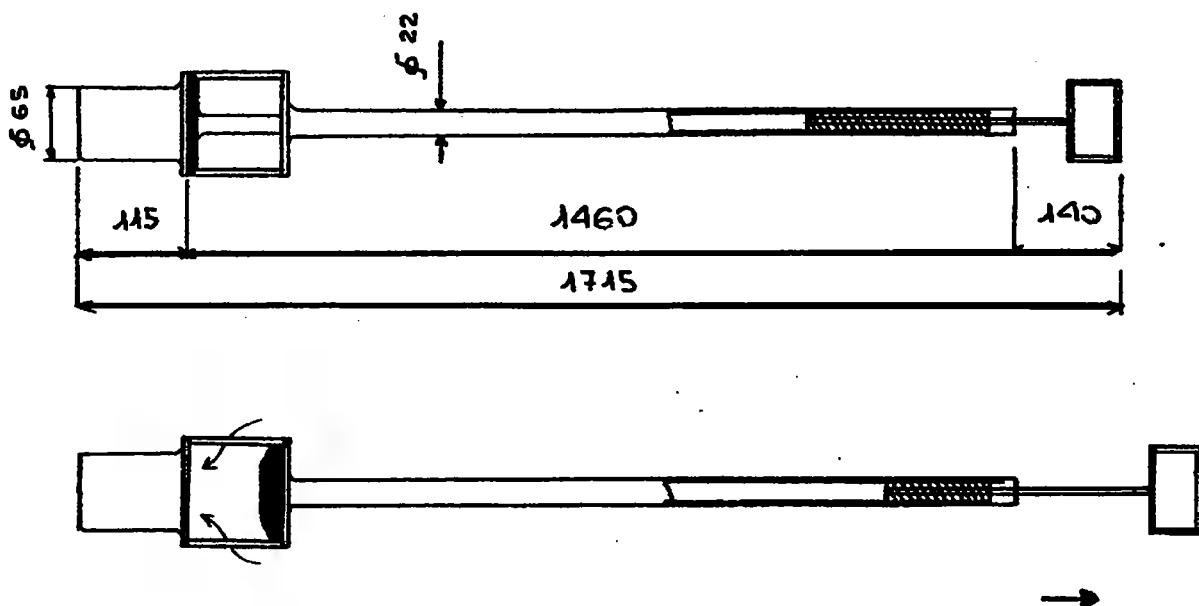
- ◆ Determination of concentration of volatile elements (SO₃, alkalis, C1) in the case of kiln systems affected by build-up formation in the pre-heater/kiln inlet area. The level of volatile elements can provide indications or, in severe cases, can serve as control parameters for the operation of the kiln, with the objective to reduce the tendency for build-up formation. Moreover, they indicate changes in the absolute and relative input of circulation elements with raw meal and fuel, and corrective actions can - if possible - be initiated.
- ◆ Determination of non-burnt combustibles introduced with the kiln feed or the secondary firing. This can be of interest for assessing the combustion efficiency of pre-calciners, or in the context of problems associated with circulating elements (locally reducing burning conditions).
- ◆ Determination of the degree of pre-calcination in pre-calciner and pre-heater kilos.

The hot meal control can be carried out on a regular basis (e.g. 1 per shift), or in the context of specific investigations, depending on the prevailing plant situation.

Sampling

Hot meal is usually sampled manually from the meal duct downstream the lowest cyclone, with a cup welded to a steel rod. For determination of remaining carbon, quenching of the sample within the sampling cup is advisable. Fig. 11 shows a sketch of a sampler with a lid to facilitate quenching without water spilling into the sample.

Fig. 11 Hot Meal Sampler.



Analysis

Accurate and sufficiently rapid analyses of the elements SO₃, alkalis and C1 require analytical instruments which do not necessarily belong to the standard equipment of a plant laboratory. Suitable methods are:

SO₃ : LECO sulphur analyser

K₂O, Na₂O : Flame photometry; atomic absorption spectroscopy

C1 : Potentiometric titration.

The determination of these elements in pressed tablets by Xray fluorescence spectroscopy a very fast method available in most plant laboratories is less accurate. Reasons for the inaccuracy are strong matrix effects and the lack of suitable calibration standards. Hot meals applied as calibration standards are chemically unstable (hydration, carbonisation) and hence not suitable. Better suited are artificial calibration standards prepared on the basis of raw meal, possibly also of clinker.

However, for practical purposes, the accuracy achievable with the XRFmethod can still be acceptable for a correct assessment of the prevailing situation regarding the levels of circulating elements.

4.7 Clinker

Purpose

The objectives of clinker control are:

- ◆ Assurance of an adequate clinker quality in view of the final product cement
- ◆ Support for an efficient kiln operation at low heat consumption.

The primary criterion of the clinker quality is the free lime content; the main consequences of inadequate free lime as a result of too weak or too hard burning are:

in the case of too high free lime:

- ◆ Loss in strength potential
- ◆ Increase of cement expansion (Le Châtelier, autoclave), to the extent of nonconformity with specifications
- ◆ Disturbances in cement grinding

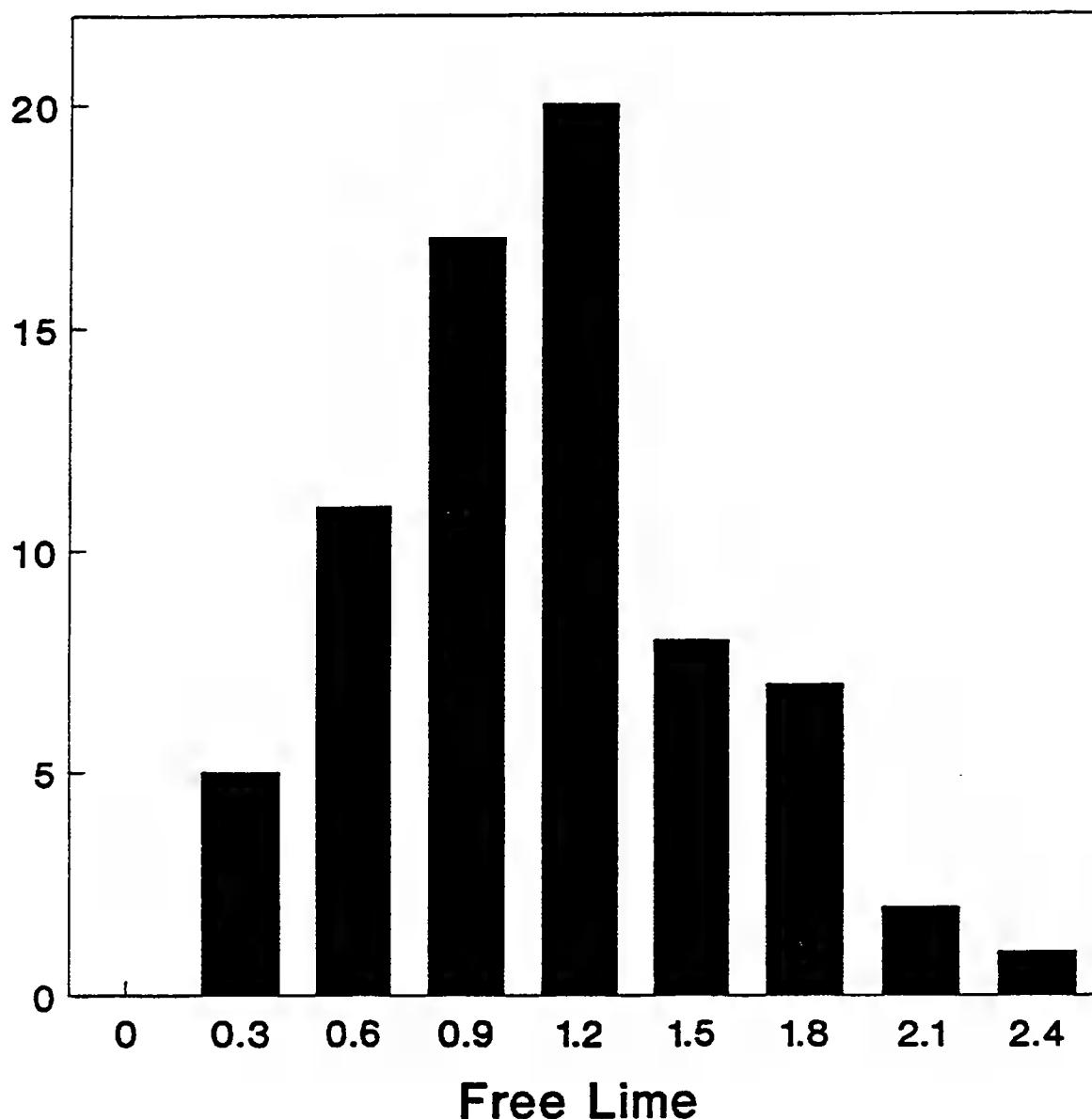
in case of too low free lime:

- ◆ Loss in cement reactivity
- ◆ Excessive heat consumption
- ◆ Poor grindability.

An adequate target free lime content has to be established individually for each production line (and clinker type). The following statistical figures for the average free lime content of the clinkers from the 'Holderbank' Group plants illustrate the range encountered in industrial clinkers (Fig. 12):

CaO _f :	x	0.96%
	s	0.45%
	min.	0.20%
	max.	2.16% (n = 71)

Fig. 12 Free Lime in Industrial Clinkers ('Holderbank' Group Plants 1988).



The target free lime content should be such that it permits a stable and economic kiln operation and that an appropriate cement quality can be achieved. Upper limits have to be defined, above which the cement quality will be seriously affected; clinker not meeting this internal specification should be stored separately and returned to the process in a controlled way.

The extent of clinker control too has to be established individually for each situation, depending on the uniformity of materials flow and general stability of kiln operation.

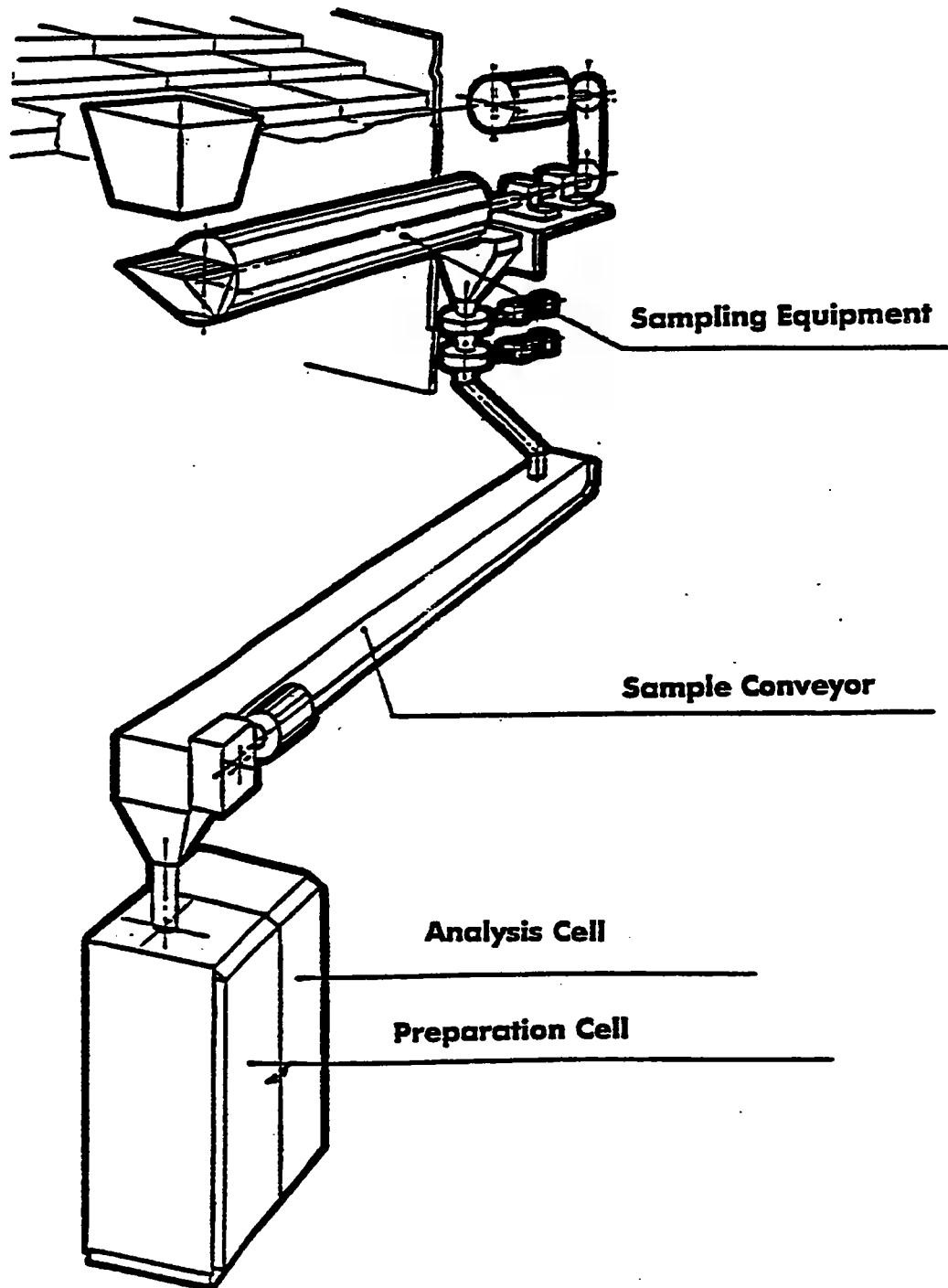
Frequent control (hourly or even more often), possibly with automated systems, can though need not necessarily in all cases lead to reduced fuel consumption and hence appreciable cost savings. The signals of the automatically determined control parameters (free lime, litre-weight) can be transmitted to and be utilised in kiln automation systems.

The free lime determination can be substituted or complemented for process control purposes by litre-weight or alkali content determination. In a number of cases good correlation's are also found with NO_x measurement.

Clinker sampling

Clinker is still mostly sampled manually from a conveyor belt. Automated clinker sampling can either be done along the clinker transport or inside of grate coolers (Fig. 13).

Fig. 13 **Clinker Sampling.**



Free lime determination

In addition to the established laboratory methods for manual free lime determination by titration (ethylene glycol method), there are different systems for automated free lime determination:

◆ **Conductometric free lime determination**

Automatic free lime analysers, particularly designed for installation outside the laboratory, e.g. close to the clinker cooler, are offered by two suppliers in France, namely ISYS and ITECA. The layout is shown in Fig. 13.

In a usual arrangement, clinker samples are taken underneath the cooler grate. Free lime is determined by extraction of the ground clinker with ethylene glycol and measurement of the resulting conductivity of the solution. A measuring cycle takes about 6 to 10 minutes. The results are transmitted to the central control room or laboratory.

Such systems are, with good experience, fairly widely applied in French and Belgium plants.

It should be noted that the conductivity measurement is influenced by soluble alkali sulphates. The calibration has to account for this, though a more or less uniform alkali sulphate content in clinker is a prerequisite for reliable measurements.

◆ **Free lime determination by X-ray diffraction**

This method is applied in a number of plant laboratories, usually in connection with the X-ray fluorescence spectroscopy and quite often integrated in automatic systems. The chemical composition and the free lime content can be determined on one and the same pressed tablet by XRF and XRD respectively. For the free lime determination, the peak intensity or integrated intensity of the CaO 200-reflection (or 220-reflection) is measured.

Calibration curves have to be established individually for each plant; due to the chemical instability of CaO_{free} containing calibration standards, secondary standards containing NiO are usually applied.

The accuracy of the method as compared to the wet chemical methods is not excellent but mostly sufficient for practical purposes (standard deviation of linear regression in the order of 0.1-0.15% CaO_f).

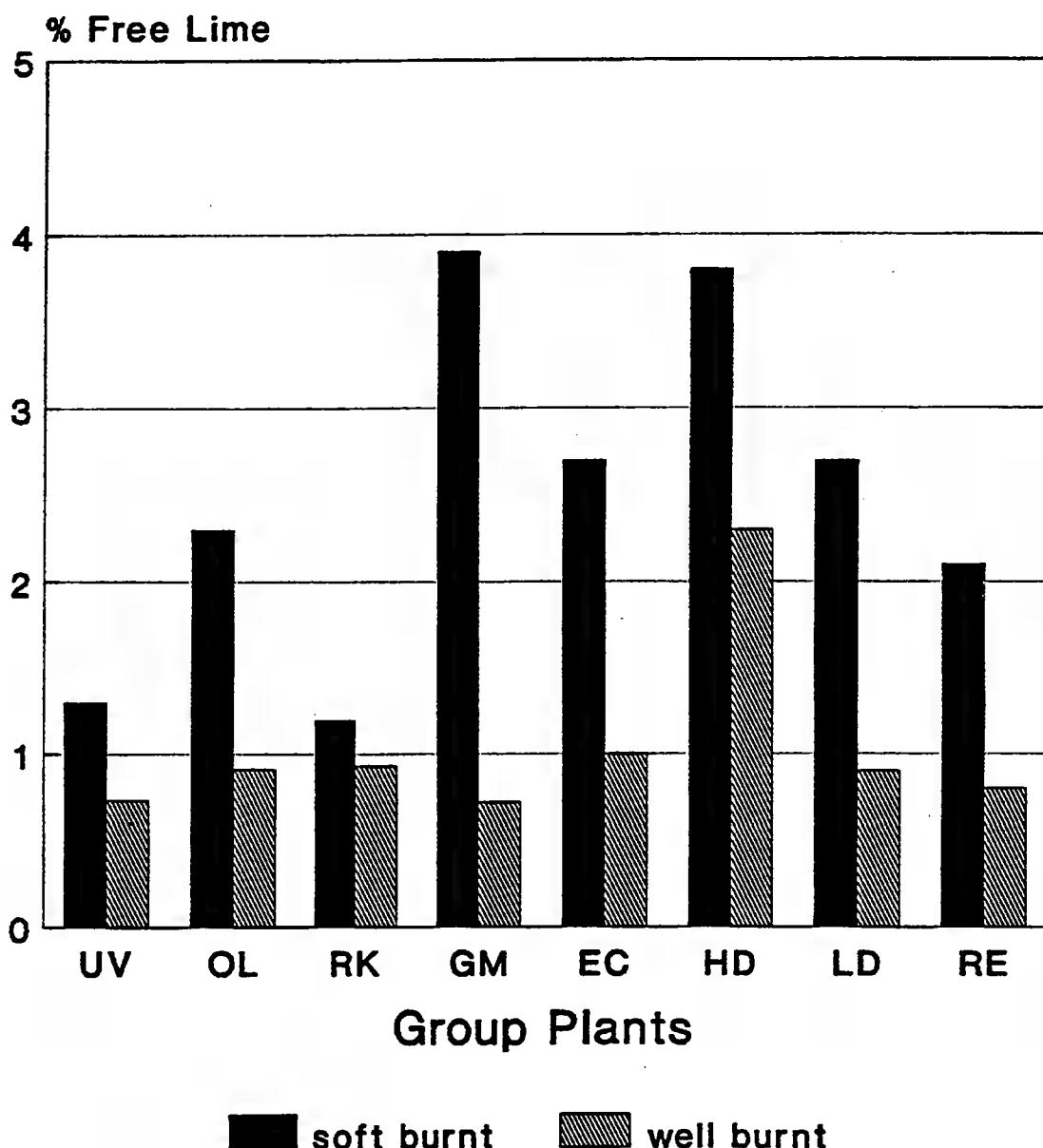
It has to be noted that only CaO_{free} is determined, in contrast to the wet chemical or conductometric method, where the sum of CaO_f and Ca(OH)₂ is measured.

Litre-weight determination

The determination of the clinker litre-weight on a sieved fraction typically 4-8 mm is a fairly fast method frequently used for clinker control on an hourly or two hourly basis. It is usually complemented by free lime determination on shift or daily composite samples.

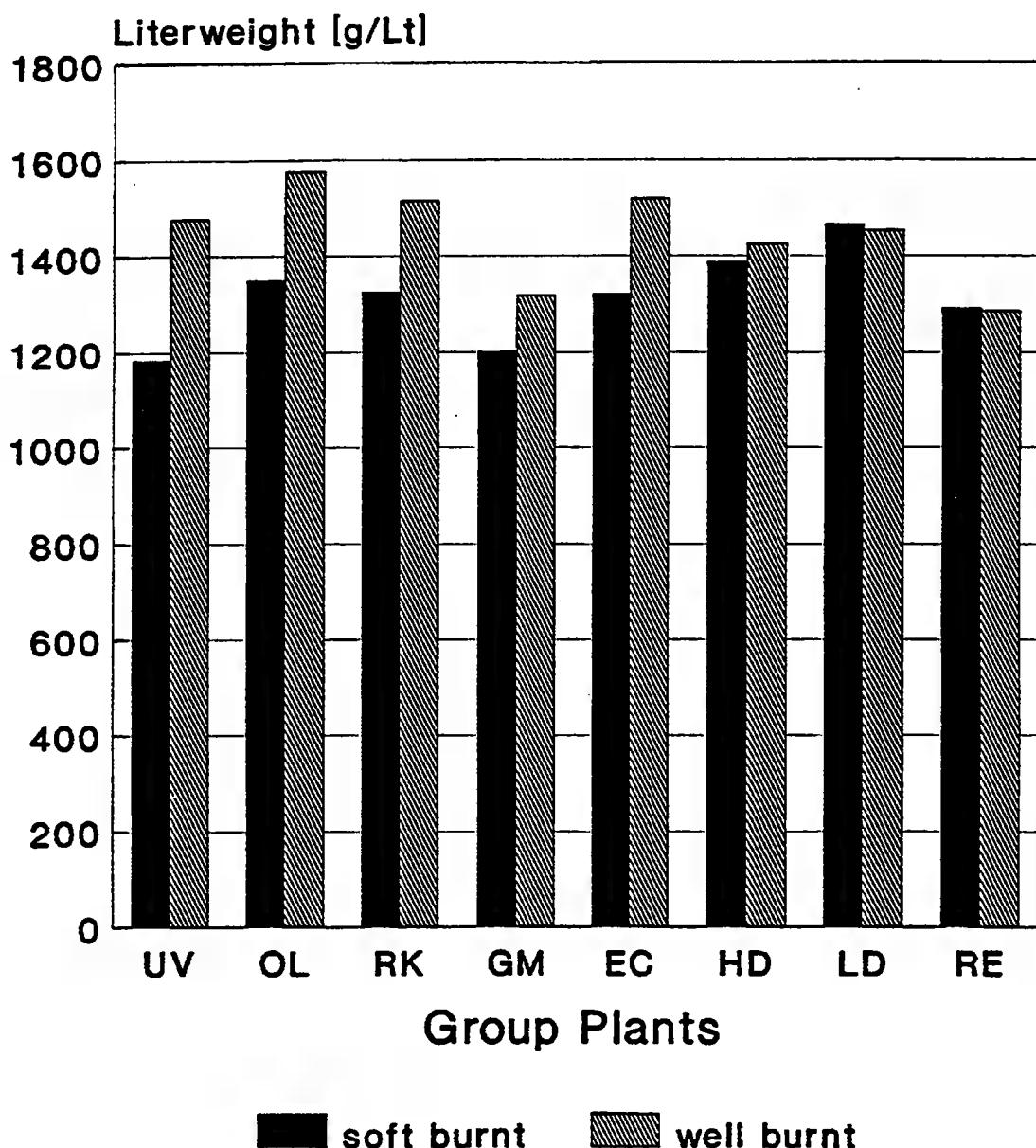
The litre-weight determination can only be applied, if there is a sufficiently good correlation with the free lime content. From Fig. 14 and 15 it can be derived that the free lime content is generally a reliable indicator of the degree of burning, whereas the litre-weight is not in all cases.

Fig. 14 Free Lime Content Soft and well burnt Clinkers.



CLINKER GRINDABILITY

Fig. 15 Litre-Weight (Soft and well burnt Clinker).



CLINKER GRINDABILITY

In those cases where the litre-weight is a good indicator of the degree of burning, the correlation with free lime can vary in dependence with the clinker composition (Fig. 16). Furthermore, the linear increase of the litre-weight with harder burning can inverse at very hard burning (Fig. 17).

Fig. 16 Correlation between Free Lime content; Litre-weight and Silica Modulus.

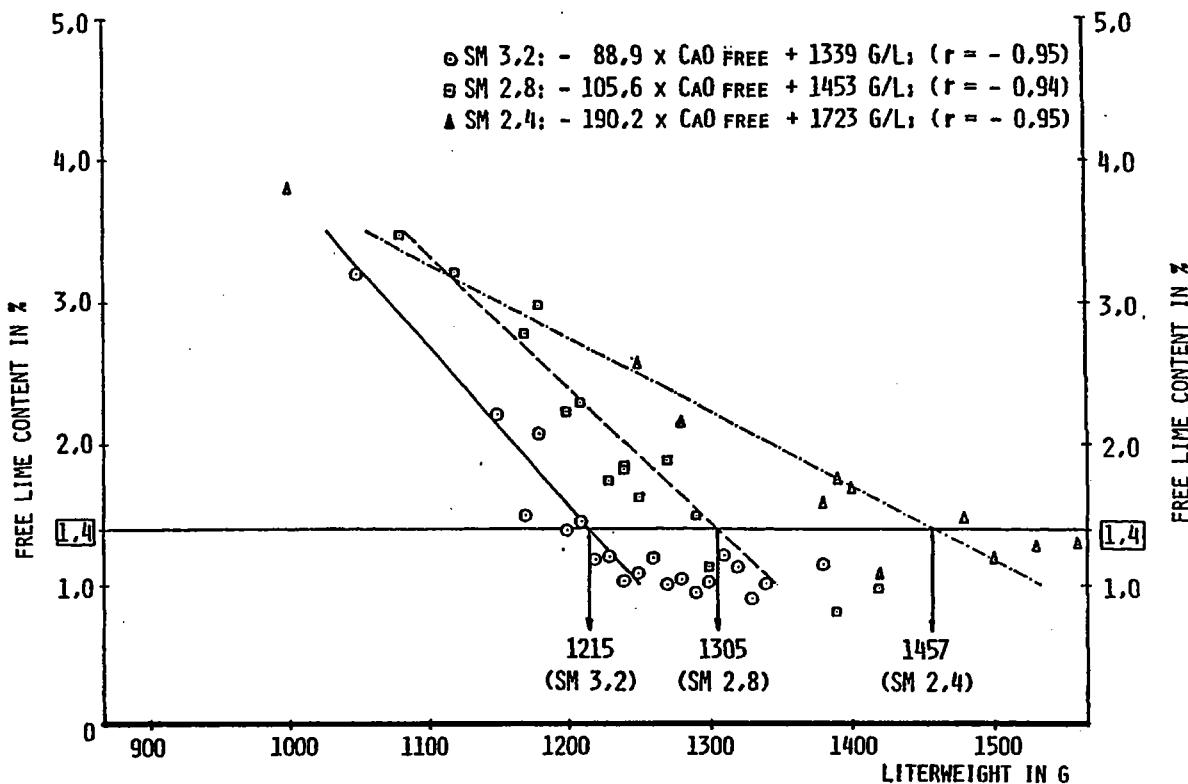
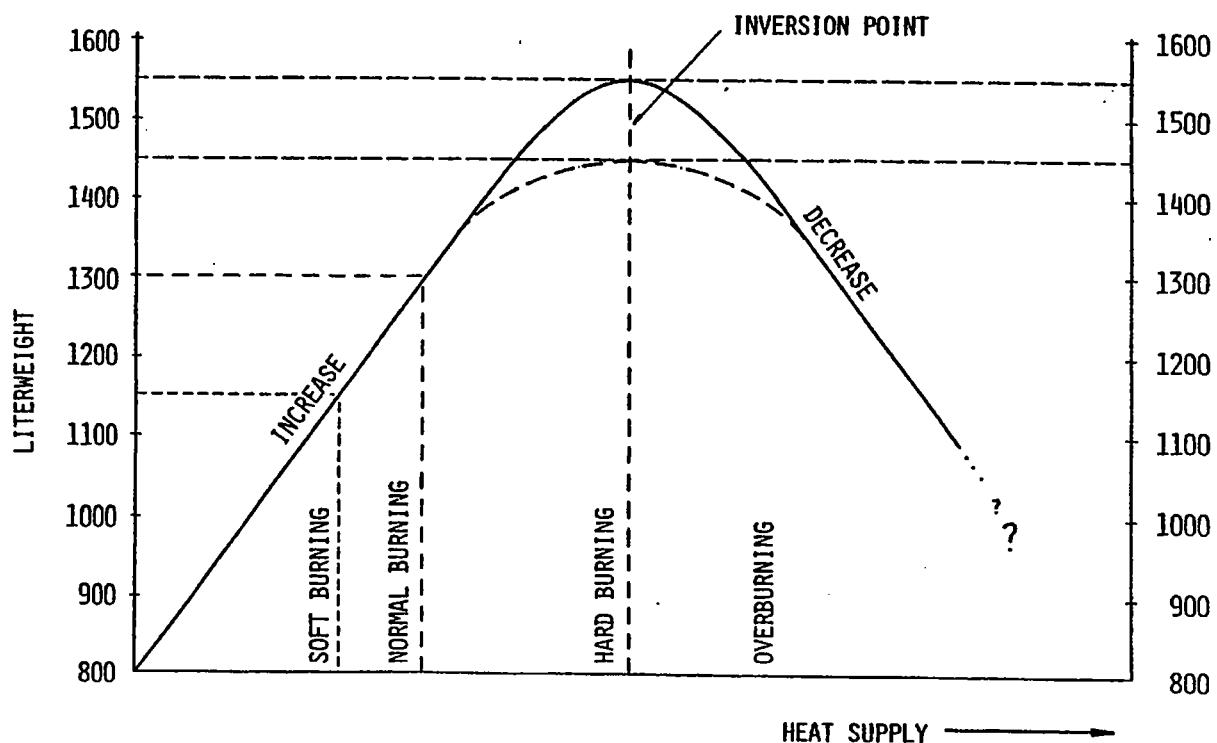
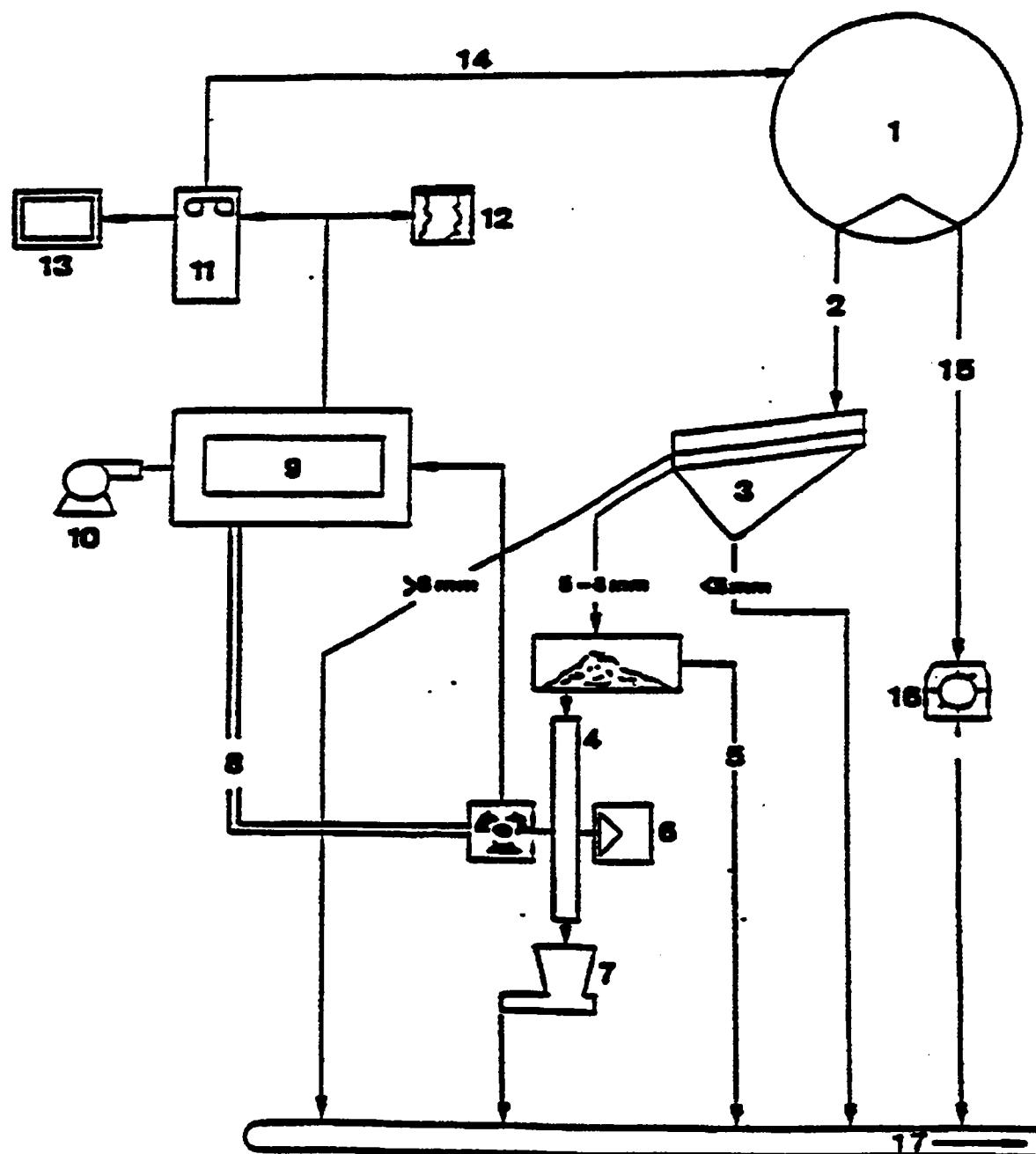


Fig. 17 Correlation between Free Lime content and Litre-weight for over burnt Clinker



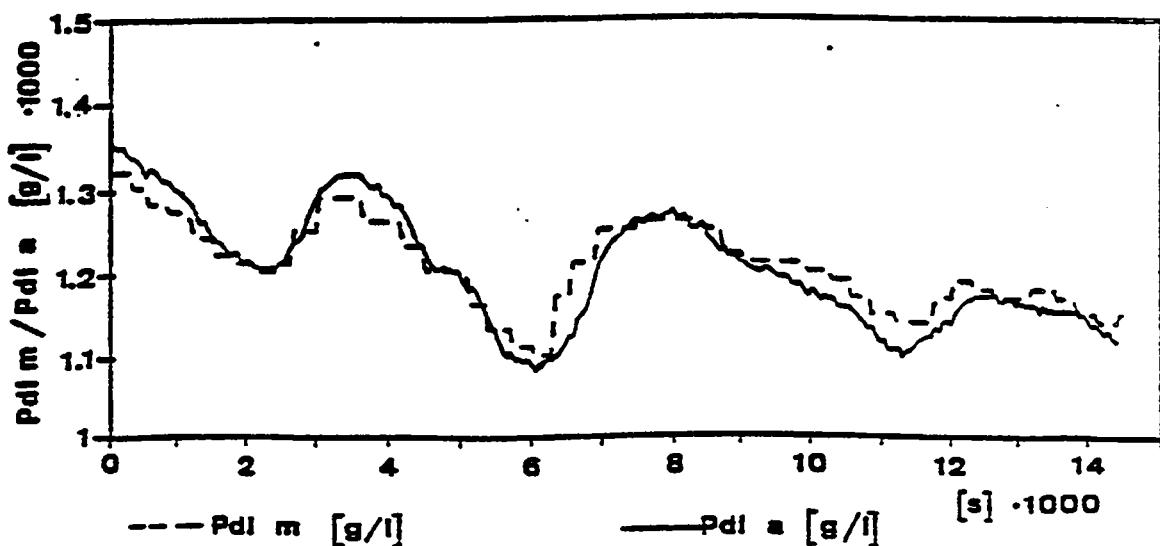
At a 'Holderbank' Group plant in Switzerland, the manual litre-weight determination has successfully been replaced by an automatic online system, measuring the apparent clinker density with a nuclear densitometer. The system is schematically shown in Fig. 18a, along with the correlation of automatic and manual litre-weight measurement (Fig. 18b). It is worth noting that the density measurement is used as the primary set point parameter for the automated kiln control system.

Fig. 18a On-line Litre-Weight Determination at Eclepens



Circuit diagram for the continuous measurement of the apparent density of clinker.

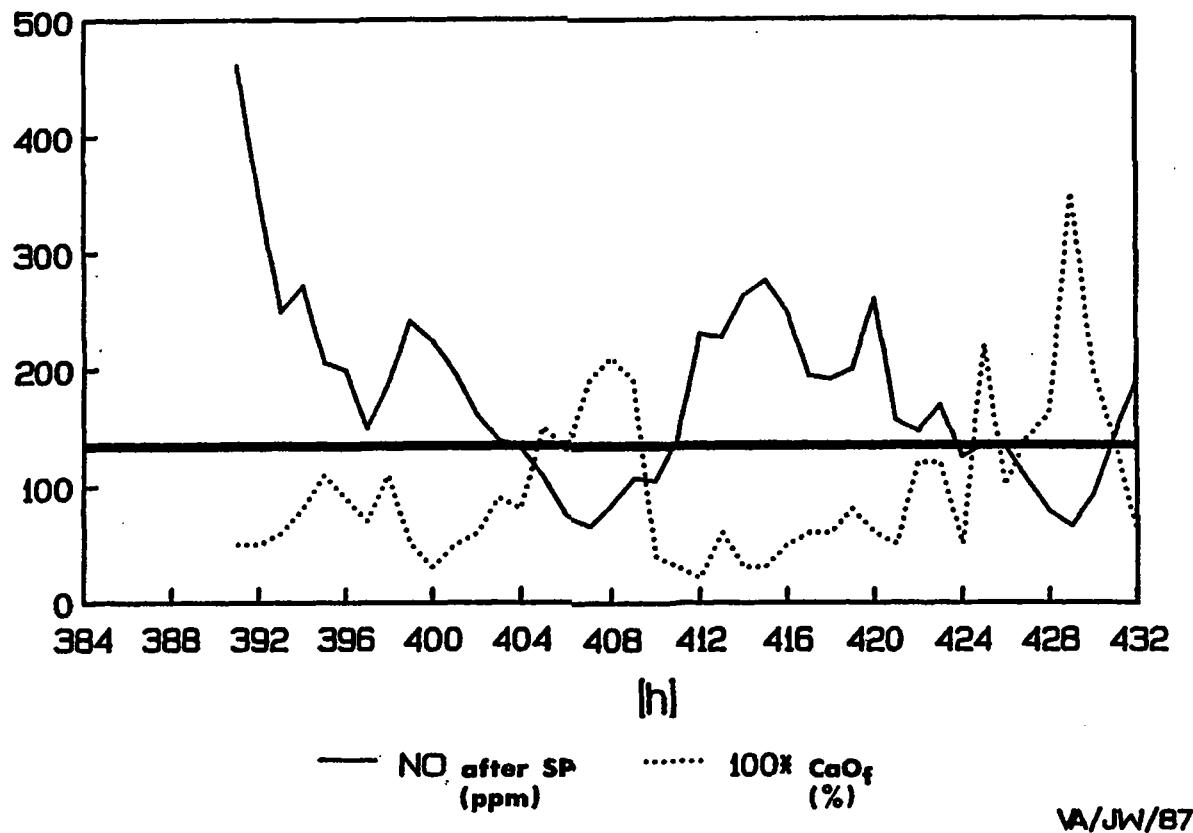
Fig 18b Manual and Automatic measurements.



Other control parameters

In a few plants, the levels of K_2O or SO_3 in clinker have been found to be the most sensitive clinker parameter with respect to the burning degree. The clinker is analysed in these cases on a hourly or two hourly basis by XRF spectroscopy.

Moreover, a correlation between the NO_x level in the kiln gas after the pre-heated and the free lime content of the clinker was established in several investigations (Fig. 19). However, this correlation can be disturbed by various factors influencing the NO_x measurement, and can, therefore, not make a clinker control altogether redundant.

Fig. 19 NO and Free Lime.

4.8 Ground Cement

Purpose

The control of the ground cement serves to ensure the designed cement quality in terms of proportioning of constituents and achievement of the required mechanical and physical properties. Since the determination of the latter is time consuming, the process control has to be based on chemical, fineness and possibly temperature parameters, for which a correlation with the cement performance has been established.

Control parameters

- ◆ For process control:
 - Fineness: Blaine
Residues (e.g. R45 ~m)
Parameter from particle size distribution (slope, size fraction)
 - SO₃: for gypsum dosage
 - Selected elements: for dosage of mineral additives
 - Temperature: to control gypsum dehydration
- ◆ For quality control
 - Standard chemical, mechanical and physical testing; usually on composite sample (e.g. daily).

Process interaction

Adjustment of feed rate and of separator speed, usually in off-line, but increasingly also in online mode.

Sampling

Automatic or manual sampling from chute, airslide or conveyor belt. Various standard types of samplers are used, typically screw samplers or air-slide sampler.

Frequency

Typically one sample per 1 to 4 hours.

Testing methods

SO ₃ :	XRF, LECO
Chemical composition:	XRF
Blaine:	<ul style="list-style-type: none">- manual or semiautomatic Blaine meter- on-line Blaine meter- on-line Gamma granulometer
Particle size distribution:	Laser granulometer.

4.9 Dispatched Cement

Purpose

Sampling and testing of the dispatched cement serves as a final verification of the cement quality. Testing of dispatched cement can be a requirement of product conformity certification schemes (so-called auto-control), or it can be requested in the context of delivery contracts to specific customers. Samples can be retained for a certain period without testing, as a reference in case of complaints.

Control parameter

Chemical composition, standard mechanical and physical properties.

Sampling

Manual or semiautomatic from silo outlet, loading device or bags. Sampling procedures described in pertaining cement standards.

Frequency

Daily or according to applicable sampling schemes. The European standard ENV 197 requests a minimum of 2 samples per week and type of cement for assessing standard conformity.

4.10 Ground Coal

Purpose

The control of fine coal is required to ensure adequate flame properties (fineness), to verify the calorific value, as well as to verify ash and sulphur content which influence clinker composition.

Control parameters

- ◆ For process control:
 - Fineness: sieve residues R90 µm, R200 µm
 - Moisture
- ◆ for verification and trend analysis:
 - calorific value
 - proximate analysis (moisture, volatiles, fixed C, ash)
- ◆ S, Cl, if required H, N (ultimate analysis)
- ◆ ash composition.

Sampling

Manual slitsampler or automatic screw sampler.

Frequency

Every 1 to 4 hours for fineness. Other tests on composite sample (e.g. daily).

Testing

- ◆ Fineness : Sieves
- ◆ Calorific value : Calorimeter
- ◆ Proximate analysis : According to pertaining standards
: Automatic proximate analyser
- ◆ Ultimate analysis : According to pertaining standards
- ◆ Sulphur : Gravimetric (fusion)
- ◆ Chloride : Titration.

5. UNIFORMITY

Significance

Uniformity is one of the most important prerequisites for smooth and efficient kiln operation.

Excessive fluctuations can easily upset the often less than robust balance of appropriate burning behaviour, thus giving rise to operational disturbances. Furthermore, since the clinker should always be adequately burnt, unnecessarily hard burning is practised for much of the production time.

Consequences are:

- ◆ high fuel consumption
- ◆ increased tendency to ring and build-up formation
- ◆ reduced brick lifetime
- ◆ fluctuations in product quality

Sources of fluctuations

- ◆ Raw components: chemical and mineralogical composition
- ◆ Raw meal: chemical and mineralogical composition, fineness; disturbances in feed rate to the mill
- ◆ Combustible: ash content, sulphur content, calorific value, fineness
- ◆ Dust return: different modes of return during direct or indirect operation
- ◆ Feed rates: equipment related fluctuations at constant settings (Kiln feed, combustibles)
- ◆ Abrupt manual adjustment of kiln operation parameters
- ◆ Abrupt and excessive adjustment initiated by automatic control loops.

Acceptable variability of kiln feed composition

Since the reduction of material variability is associated with costs for homogenisation and control, an acceptable, optimised target has to be established for each specific situation. Raw meals or clinkers of an extreme composition (e.g. LS close to 100, high SR, low AR) or with unfavourable fineness characteristics require more stringent variation limits than easy to burn clinkers. What eventually can be achieved depends on the complexity of the raw material situation, the pre-blending and homogenising facilities as well as on the efficiency of the quality control system.

Some values which are considered to provide a good basis for kiln operation, even when using difficult materials, are given below.

Guide values for feed variations

- ◆ Accuracy of the feed system: 1 to 1.5%
- ◆ Regular calibration of the system mandatory

Guide values for good chemical uniformity of the kiln feed

(for random samples over 24 h; on raw meal rather than clinker basis)

	Without analytical error	Including analytical error
Titration method max.	$s = 0.2\% \text{ CaCO}_3$ $s = 0.3\% \text{ CaCO}_3$	$s = 0.25\% \text{ CaCO}_3$ $s = 0.35\% \text{ CaCO}_3$
XRF method: max.	$s = 0.2\% \text{ CaO}$ $s = 0.17\% \text{ CaO}$	$s = 0.15\% \text{ CaO}$ $s = 0.20\% \text{ CaO}$
SiO_2	$s = 0.07\% \text{ SiO}_2$	$s = 0.2\% \text{ SiO}_2$
Al_2O_3	$s = 0.07\% \text{ Al}_2\text{O}_3$	$s = 0.2\% \text{ Al}_2\text{O}_3$
Fe_2O_3	$s = 0.04\% \text{ Fe}_2\text{O}_3$	$s = 0.2\% \text{ Fe}_2\text{O}_3$
LS	$s = 0.7$	$s = 1.2$
SR	$s = 0.04$	$s = 0.06$
AR	$s = 0.06$	$s = 0.08$

Means of improving uniformity

The kiln feed uniformity is a result of various factors along the preparation process, starting from the raw material deposits and going through several stages of homogenisation and blending.

Possibilities for improvements can be found in the following areas:

- ◆ **Exploitation planning**
Medium to long-term exploitation planning, based on accurate raw materials inventory. Application of computer based methods.
- ◆ **Quarry scheduling**
Short-term quarry scheduling, based on blast hole dust analysis. Application of computer based methods.
- ◆ **Raw material and coal pre-blending**
- ◆ **Blending control**
Blending control at integrated pre-blending stockpile and raw mill. Appropriate selection of sampling regime and analytical methods. Various degrees of automation from manual to online, or even to 'real-time' with bulk material analyser.
- ◆ **Raw meal homogenisation**

6. EXTENDED QUALITY CONTROL

In addition to the basic test methods for routine control, a large variety of sophisticated methods and procedures is applied for material technological investigations in connection with special manufacturing and application problems and in research and development. Characterisation of raw materials, clinker, additives, etc. is not only limited to chemical analysis, but also the mineralogical and textural features are important. Thermo-analytical (DTA, TGA), microscopic (light and electron microscope) and X-ray diffraction (XRD) methods are used as routine procedures in this context. Microprobe is a powerful tool to determine the elemental composition of individual clinker minerals. Burnability and volatility tests are used to assess the raw mix behaviour in the industrial kilos.

Although most of these methods are only applied in central or research laboratories, some of them are also used in a number of plant laboratories for routine quality control, such as X-ray diffraction to monitor the quartz and clay minerals of raw materials and to examine free lime in clinker; or differential thermal analysis to control the dehydration of gypsum in cement during the grinding process. However, if these specialised testing procedures are promoted too much, there is the danger that they might finally be included in the standard specifications. This has to be avoided because it would make the quality control procedures too sophisticated and expensive for the majority of plants.

In addition to the traditional tasks and methods of quality control, in many plants the scope of control is significantly extended, not only due to more stringent process conditions and to higher quality requirements and special requests by the customers. The following tasks require extended application of already established quality control methods or even introduction of new techniques:

- ◆ Refractories testing, to ensure the material quality of the installed kiln brick lining which requires apart from visual inspection extended chemical analysis, simple physical and thermal tests.
- ◆ Quality control of additives for production of blended cements; depending on the kind of additive, its source and supply conditions, more or less extensive chemical, mineralogical and performance tests have to be carried out; with the increasing use of industrial by-products, such as fly ashes, slags, etc., efforts are also undertaken to establish reliable and rational methods for their control and for their determination in blended cements.
- ◆ The Blaine value for control and characterisation of cement fineness with respect to grinding process and cement quality is only of limited significance. therefore, grain size analysis by laser diffraction or automatic sedigraphs is used increasingly for quality and process control; in the future, the laser diffraction technique might even be used in online installations.
- ◆ Use of waste materials as raw mix components and particularly as combustibles (e.g. tyres, colliery wastes, battery casings, chemicals, etc.) require adaptation of existing or new testing methods.
- ◆ Last but not least environmental concerns and the resulting pressure upon industries force plants to extend their quality control into the area of emission control (and, in some instances, even emission control); this implies development and refinement of techniques for gas analysis especially for SO₂, NO_x, but also for hydrocarbons as well as for dust determination and collection; analysis of traces in the ppm or even the ppb-range for toxic elements such as Ti, Cd, Pb, Hg, etc., nowadays is not an unusual task for the cement industry.

